May 19, 1936. E. MARX 2,041,663

MEANS FOR CONVERTING ALTERNATING CURRENT INTO DIRECT CURRENT AND VICE VERSA

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Fig. 1.

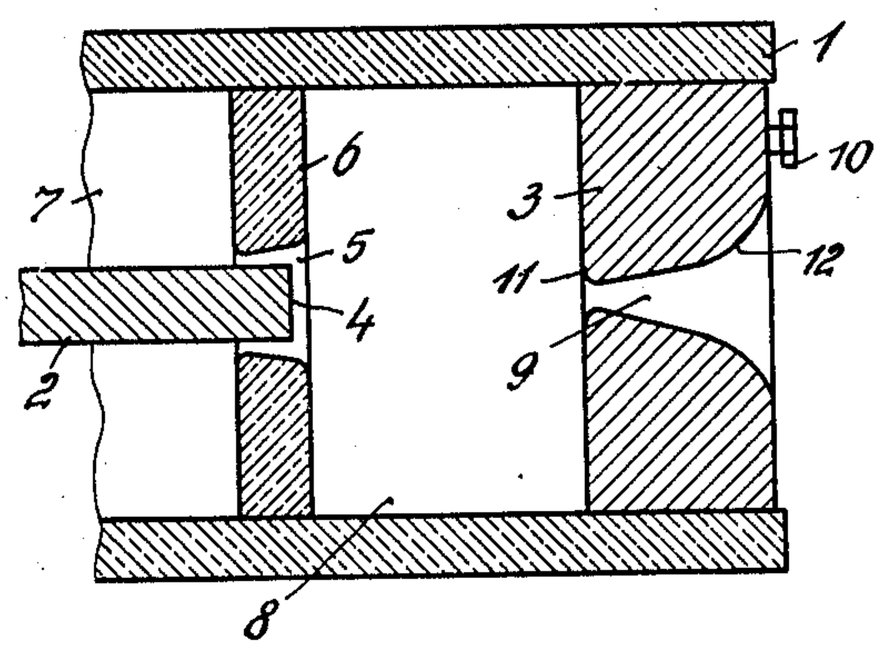
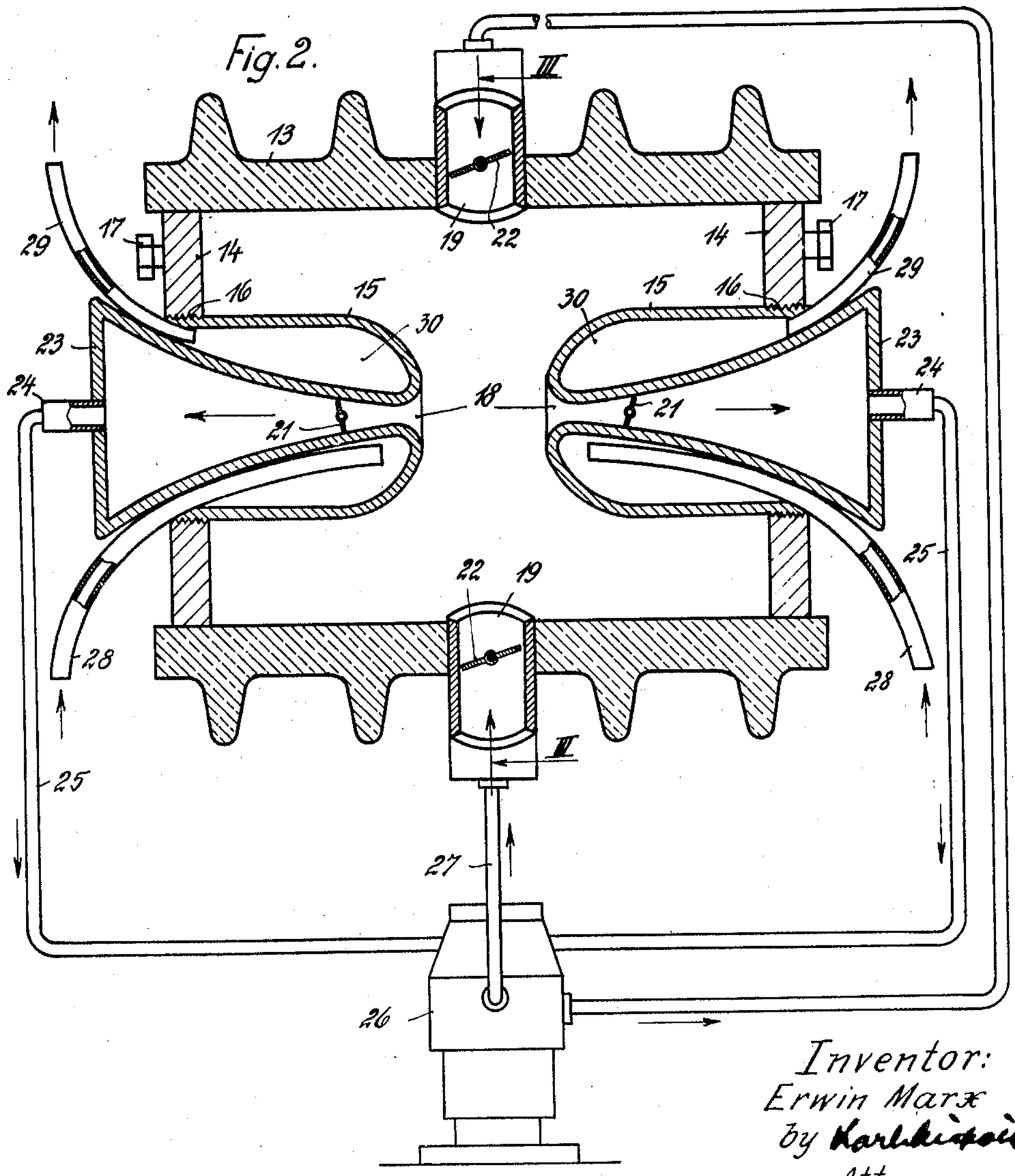



Fig. 2.




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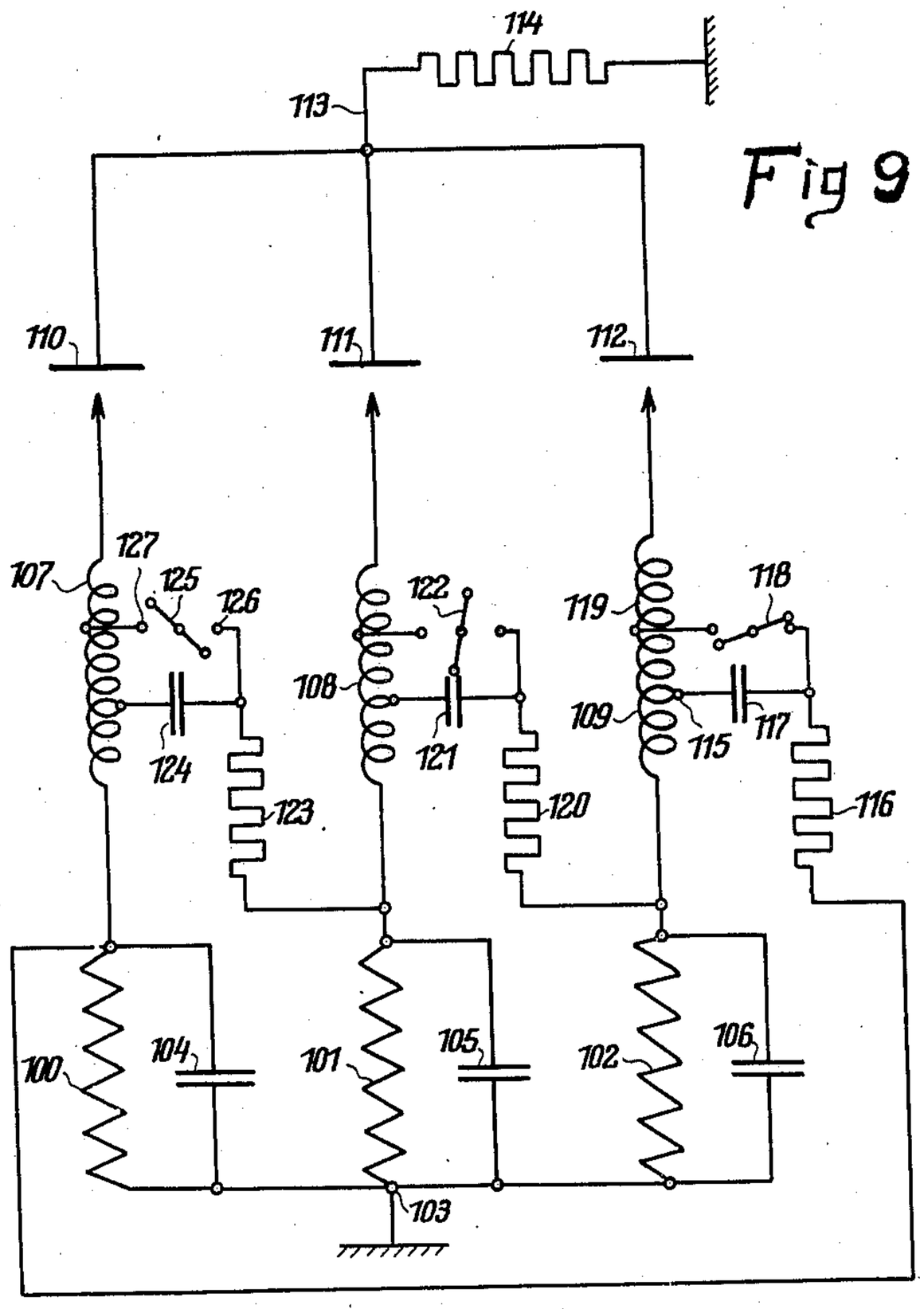



Fig 9

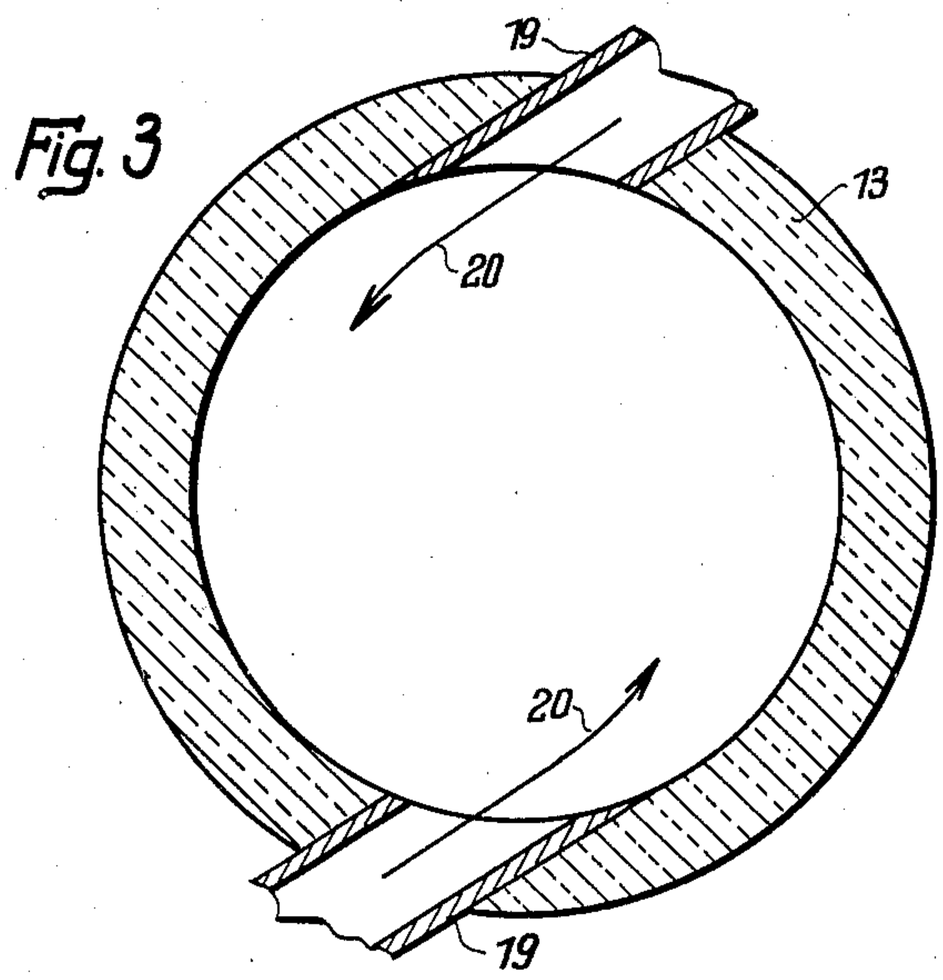



Fig. 3

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MEANS FOR CONVERTING ALTERNATING CURRENT INTO DIRECT CURRENT AND VICE VERSA

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Fig. 5.

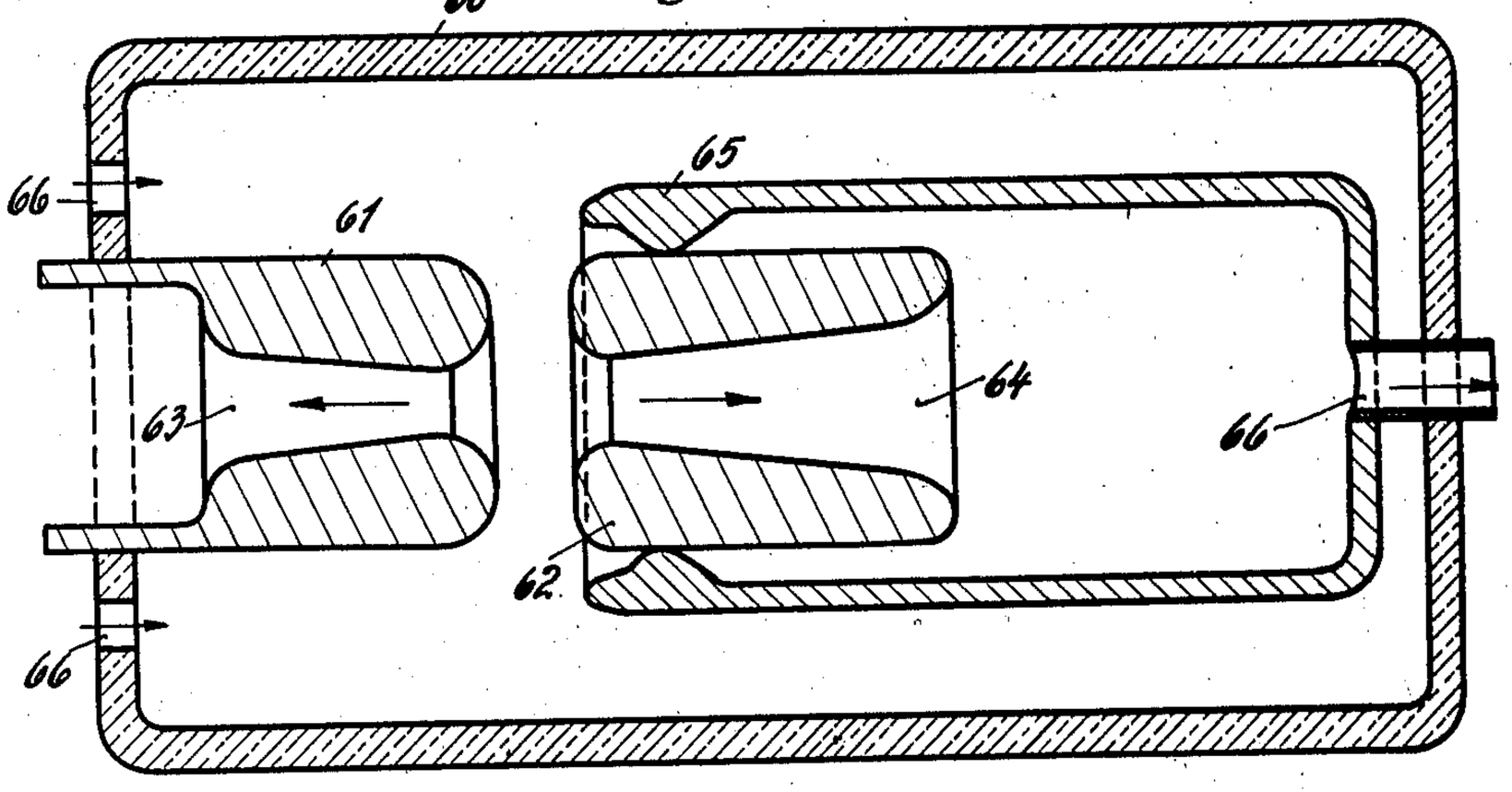
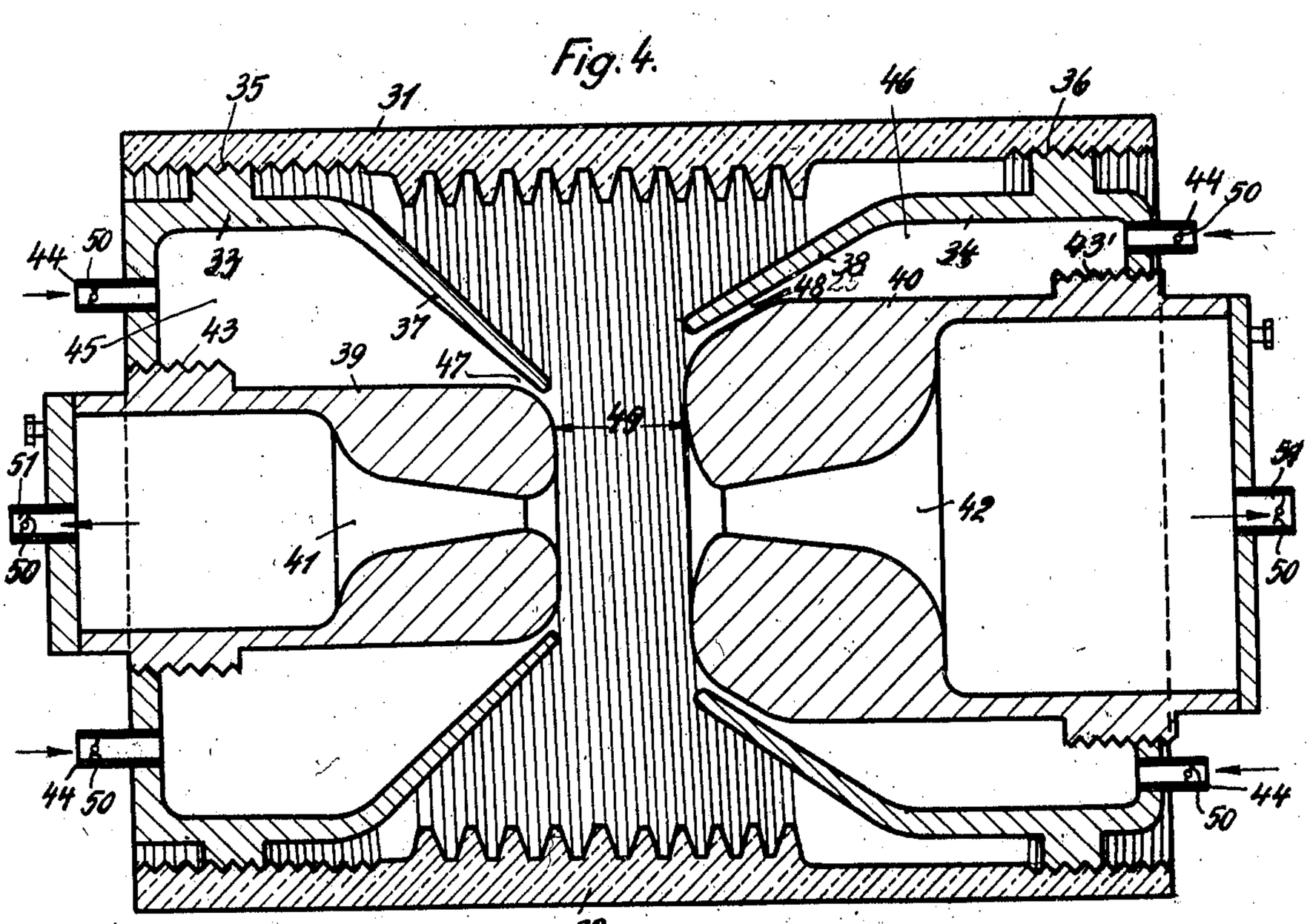



Fig. 4.




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MEANS FOR CONVERTING ALTERNATING CURRENT INTO DIRECT CURRENT AND VICE VERSA

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Fig. 6.

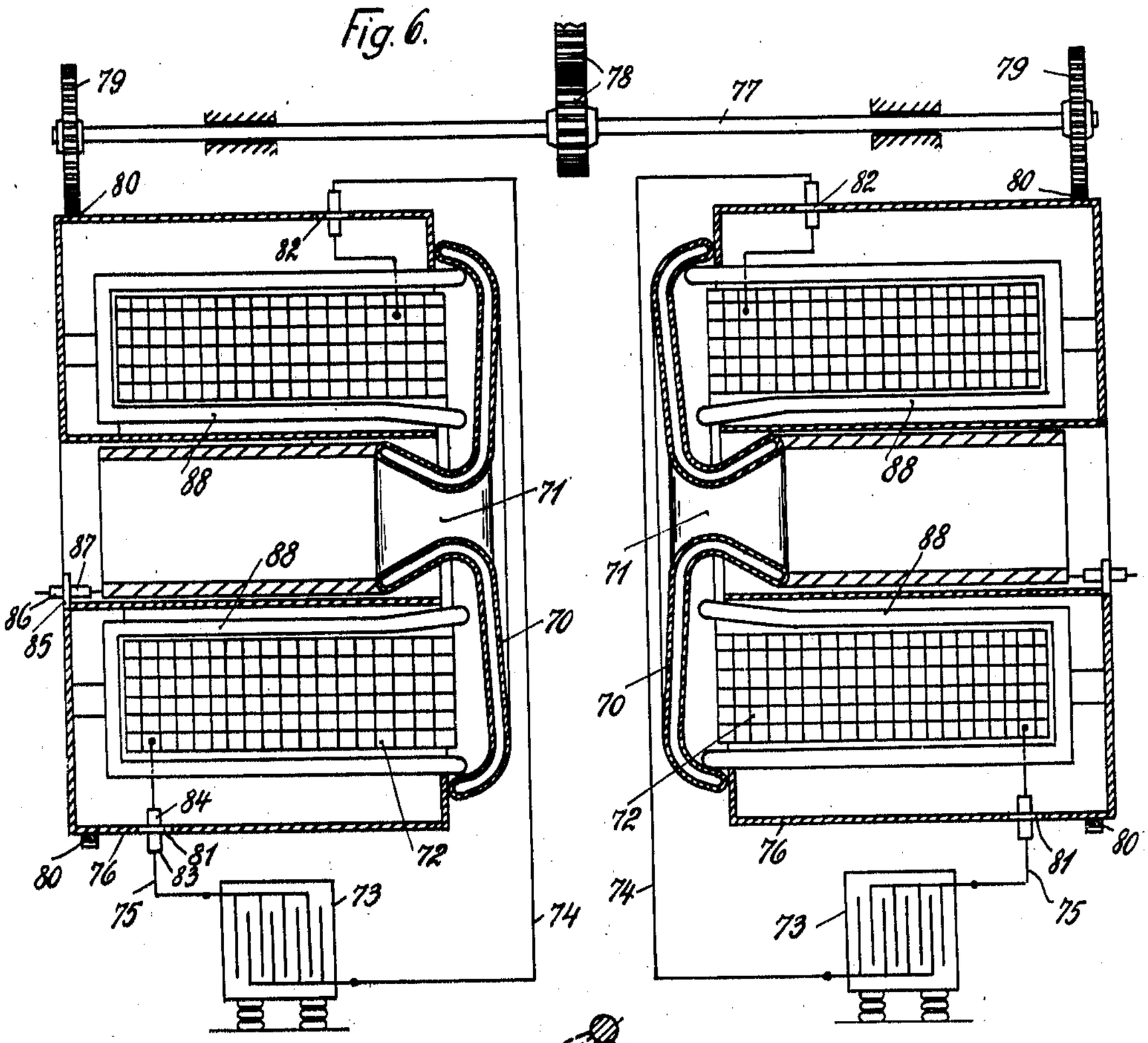
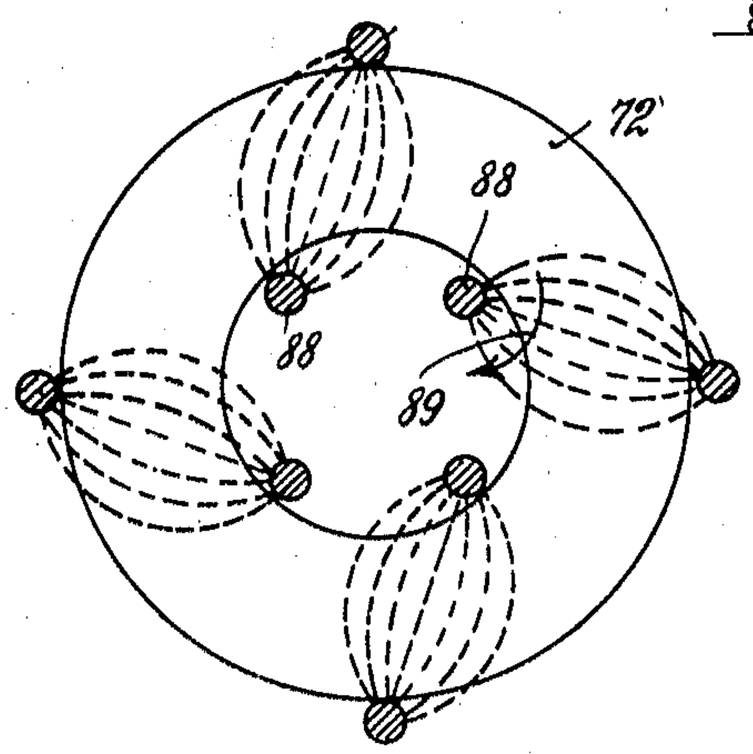



Fig. 8.




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MEANS FOR CONVERTING ALTERNATING CURRENT INTO DIRECT CURRENT AND VICE VERSA

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Fig. 7

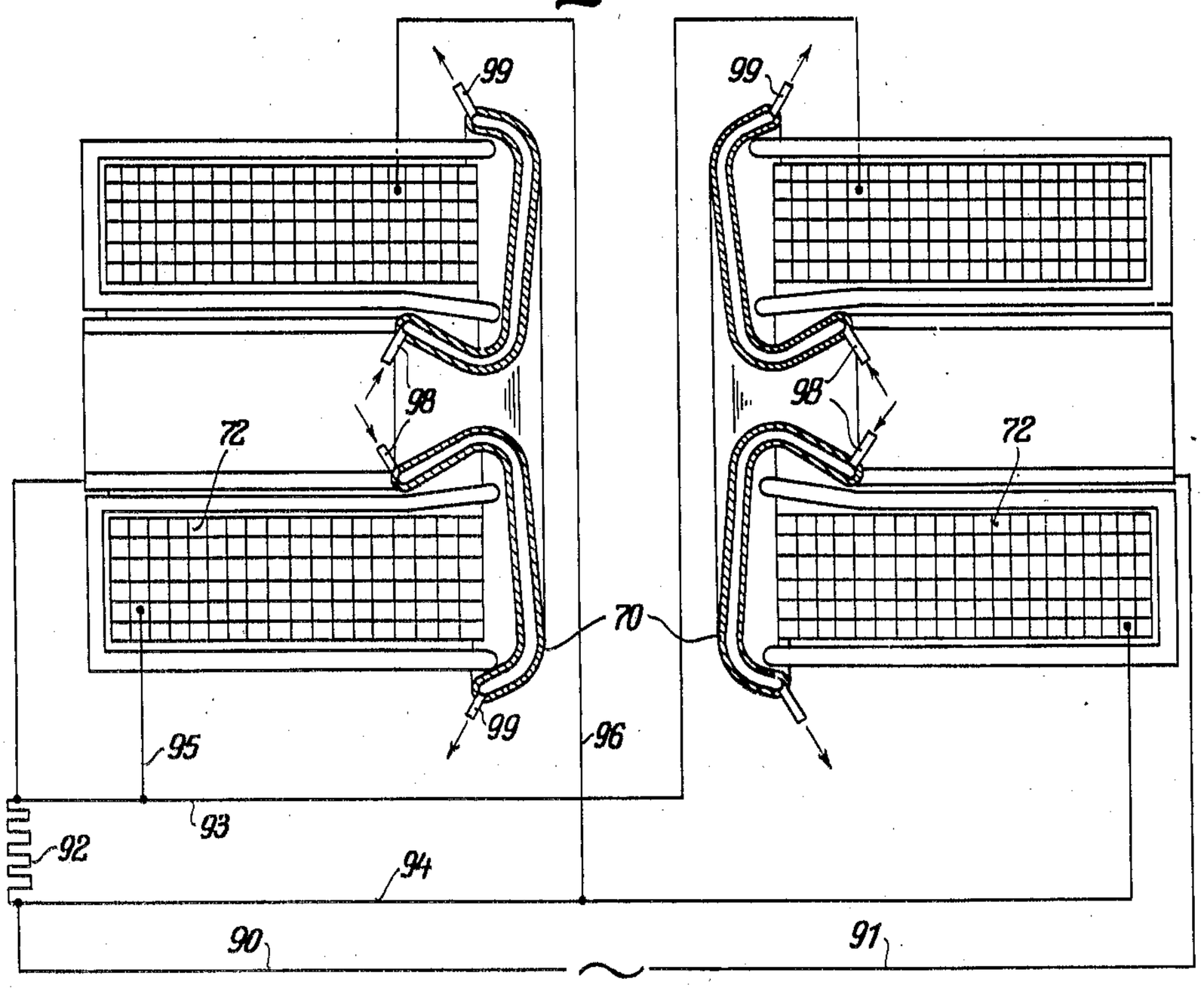
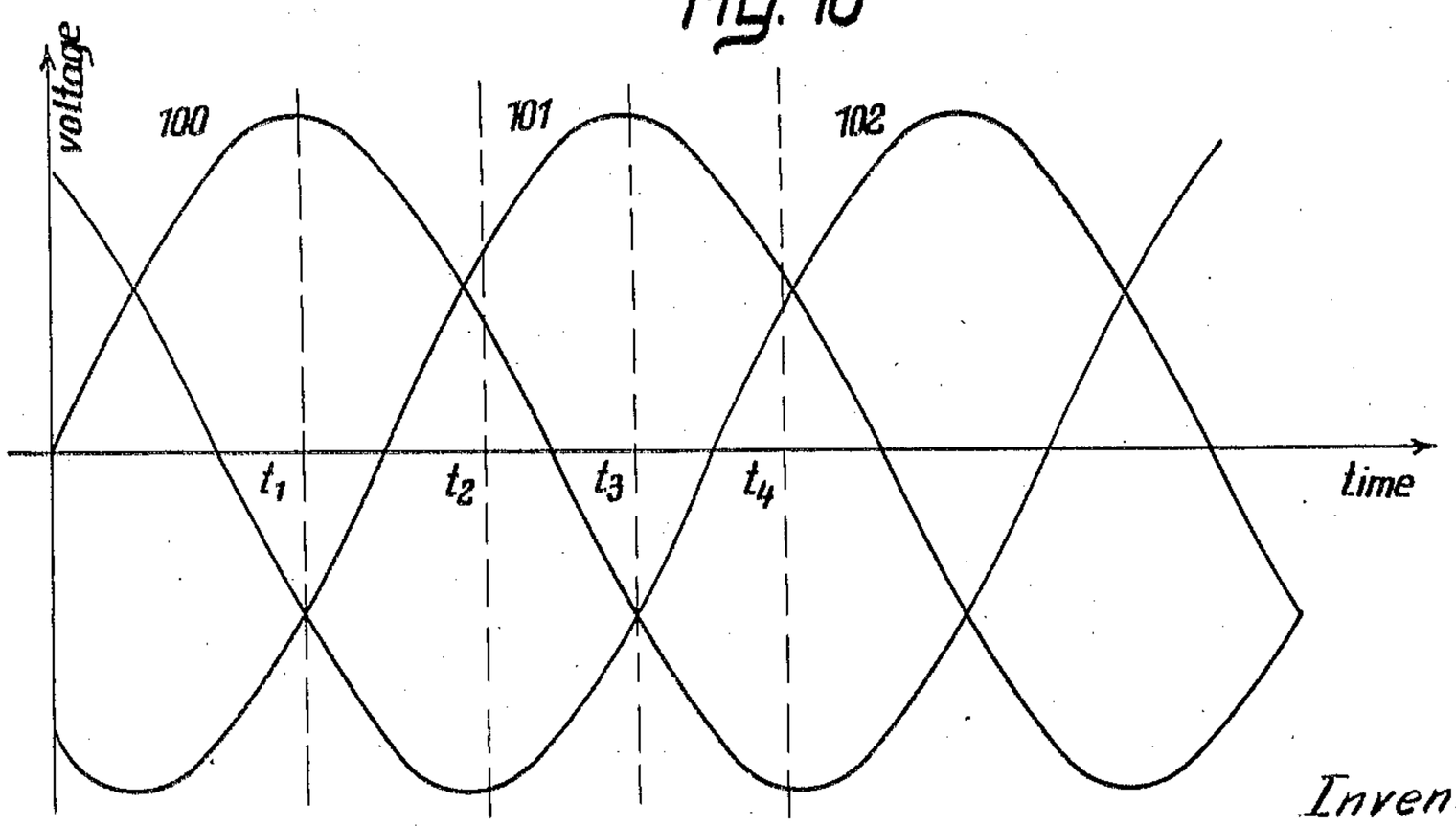



Fig. 10



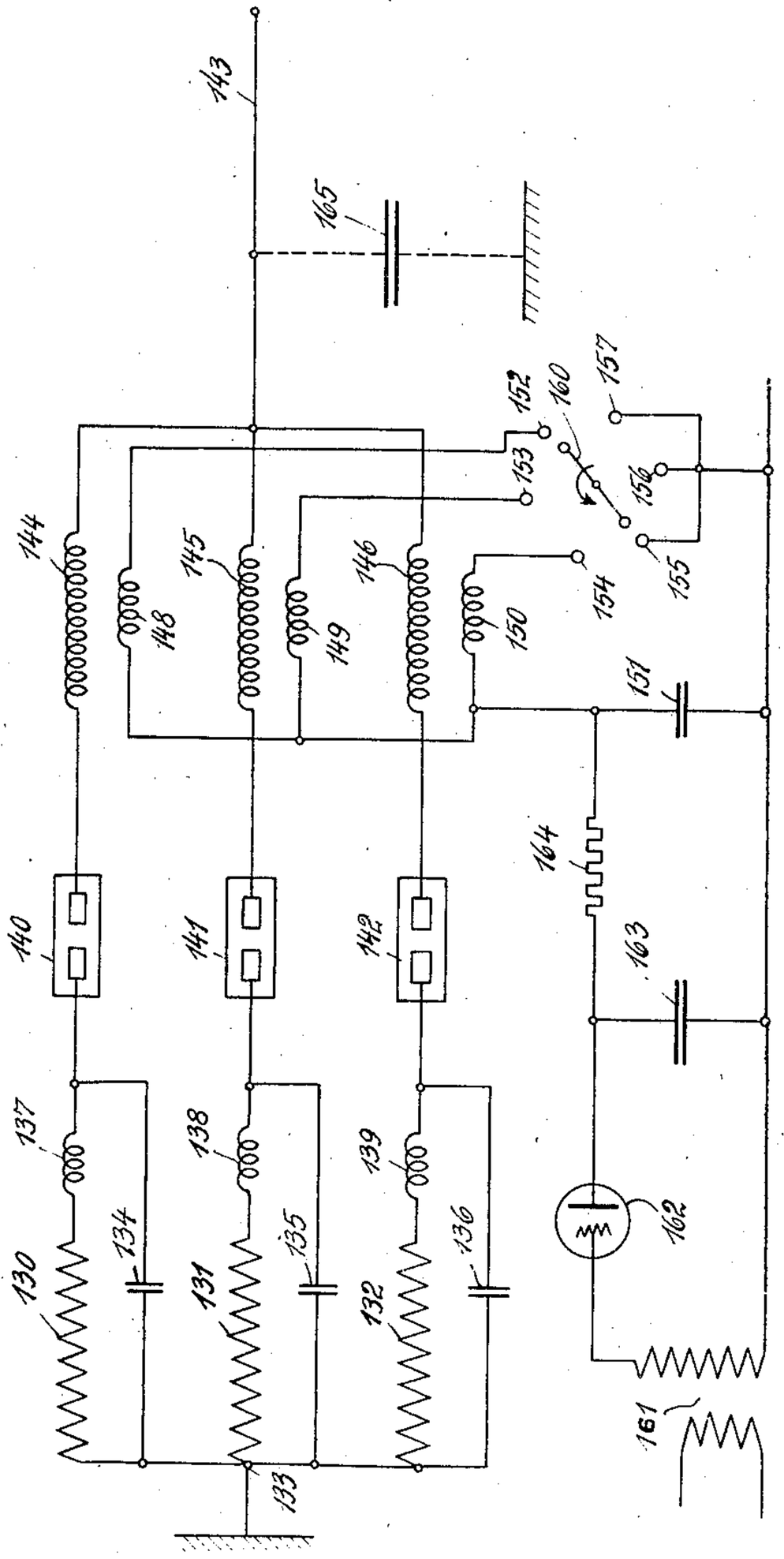

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MEANS FOR CONVERTING ALTERNATING CURRENT INTO DIRECT CURRENT AND VICE VERSA

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Fig. 11.



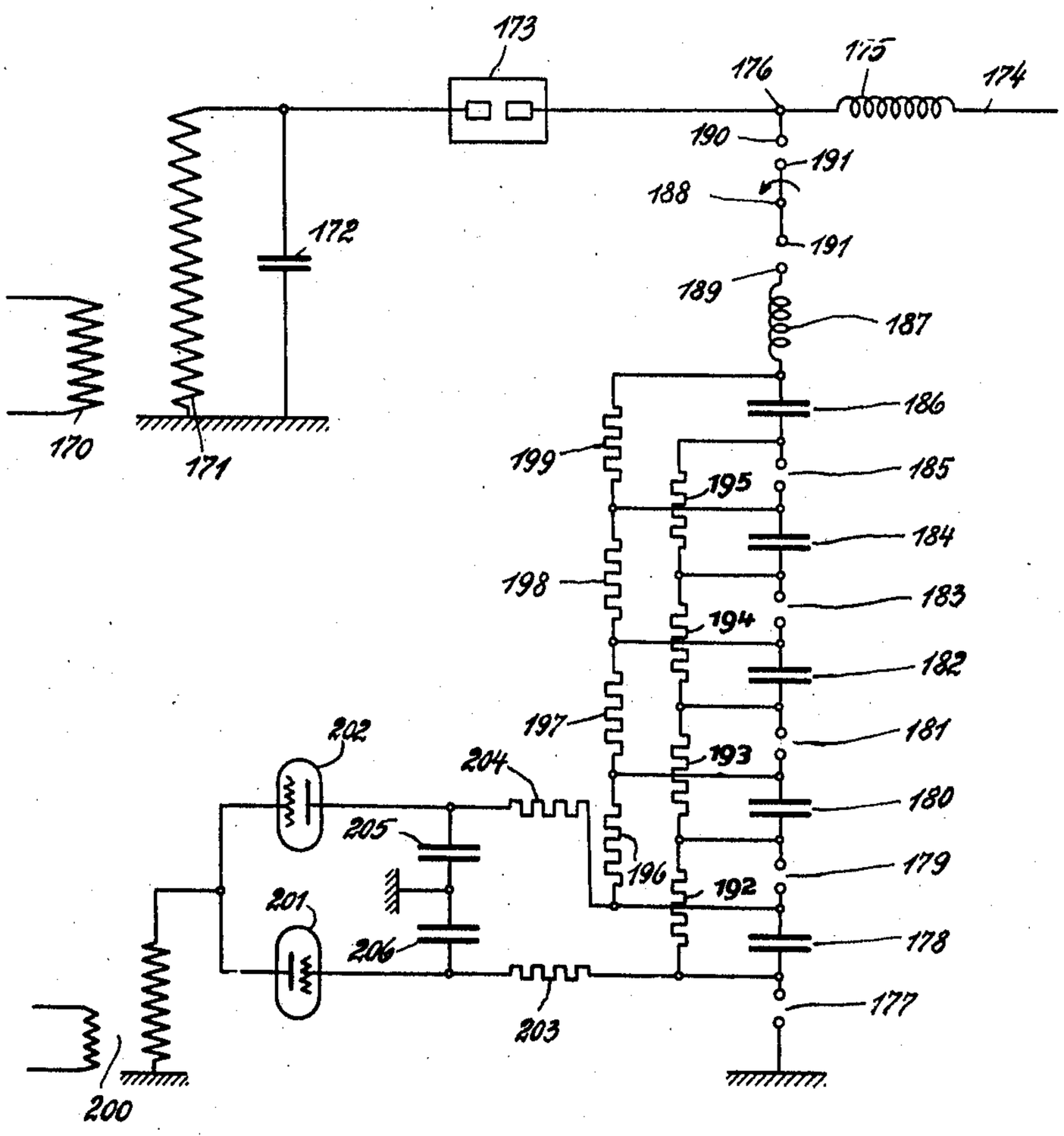

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MEANS FOR CONVERTING ALTERNATING CURRENT INTO DIRECT CURRENT AND VICE VERSA

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Fig. 12.




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Patented May 19, 1936 2,041,663

# UNITED STATES PATENT OFFICE

2,041,663

## MEANS FOR CONVERTING ALTERNATING CURRENT INTO DIRECT CURRENT AND VICE VERSA

Erwin Marx, Brunswick, Germany

Application January 14, 1932, Serial No. 586,622
In Germany January 22, 1931

34 Claims. (Cl. 175—363)

My invention relates to means for converting alternating current into direct current and vice versa and more especially to spark gaps adapted for use in equipments of this kind.

It has already been proposed to convert voltages by means of spark gaps. Such conversion, however, could not be carried out in practice with large current intensities because a regular and secure extinguishing of the arc could not be obtained since the contacts of the spark gaps were heated by the arc to inadmissibly high temperatures. The same difficulty occurs in spark gaps used in connection with switches or the like. In order to extinguish the arc it has been suggested to quench the arc by means of compressed air; however in the known devices, a large quantity of compressed air is required for quenching the arc and even then the arc will not be extinguished with certainty so that an efficient conversion of voltages and currents cannot be obtained in this manner.

It is an object of my invention to overcome these difficulties. To this effect I provide a pressure chamber containing spark gap electrodes, means for feeding compressed air to this chamber and a nozzle-shaped orifice in at least one electrode so that the base point of the arc is driven towards the orifice by the compressed air.

It is a further object of my invention to provide spark gap electrodes with nozzle-shaped orifices and to shape the electrode in such manner that the arc is lengthened by the wandering of the base points along the electrode only when the base points have entered the nozzle-like orifices of the electrode.

It is another object of my invention to provide means for rendering effective the arc-quenching means, for instance compressed air, at predetermined moments depending upon the variation of the alternating current to be interrupted.

It is a still further object of my invention to provide means for converting alternating current into direct current and vice versa comprising spark gaps of the kind referred to and in connection with such converting means to provide means for initiating a flash-over in the spark gaps at predetermined times.

In the drawings affixed to this specification and forming part thereof some embodiments of my invention are illustrated diagrammatically by way of example.

In the drawings

Fig. 1 is a longitudinal section of a spark gap according to my invention,

Fig. 2 is a longitudinal section of another embodiment of a spark gap showing diagrammatically the piping for the compressed air.

Fig. 3 is a cross section along the line III—III of the spark gap shown in Fig. 2,

Figs. 4 and 5 are longitudinal sections of two further embodiments of spark gaps according to this invention,

Fig. 6 is a diagrammatic view, partly in section, of another embodiment provided with blow-out coils,

Fig. 7 is a modified embodiment of the spark gap shown in Fig. 6,

Fig. 8 is an end view of a blow-out coil of the spark gaps illustrated in Figs. 6 and 7,

Fig. 9 is a diagrammatic view of an equipment for converting alternating current into direct current or vice cersa,

Fig. 10 is a diagram illustrating the operation of the equipment shown in Fig. 9,

Figs. 11 and 12 are diagrammatic illustrations of another embodiment of converting equipment according to this invention.

Referring now to the drawings and first to Fig. 1, 1 is a casing of insulating material and 2 and 3 are fixed spark gap electrodes. The electrode 2 is cylindrical and projects with its forward end 4 into the orifice 5 of a transverse insulating wall 6 subdividing the interior of the casing 1 into chambers 7 and 8. The electrode 3 is a disc-shaped electrode provided with a nozzle-shaped orifice 9 and a connecting terminal 10.

The operation of this device is as follows: When a flash-over has produced an arc between electrodes 2 and 3 and this arc shall be extinguished, compressed air is introduced into chamber 7 by means of a suitable device (not shown). The compressed air will flow through the nozzle 5 into chamber 8. Since the air current is very strong in the opening 5, the base point of the arc will be driven towards the flat portion 4 of electrode 2. On the opposite side the air will escape through the nozzle 9 and the air flowing from the chamber 8 to the inlet 11 of the nozzle will drive the base point of the arc towards the nozzle inlet. When the base point has reached the nozzle inlet it will be driven with high velocity from the inlet 11 towards the flaring portion 12. Be it assumed that the current forming the arc is an alternating current, then the arc will be extinguished when the current passes through zero and the arc will not be initiated again since the electrodes have been cooled by the air current and no free electrical particles are in their vicinity.

Referring now to Fig. 2 illustrating a spark gap operating substantially in the same manner as the spark gap shown in Fig. 1, 13 is a casing of insulating material provided with two metal end walls 14 in which the spark gap electrodes 15 are fitted by means of a slot and key connection 16 so as to permit a longitudinal adjustment of the electrodes. 17 are terminal connections. Both electrodes are provided with nozzle-like orifices 18 through which the compressed air escapes. 19 are entering tubes for the compressed air provided in the wall of the casing 13. The electrodes 15 are shaped in such manner that the flash-over will occur between them at a lower voltage than along the inner wall of the casing 13. The flash-over voltage can be adjusted by suitable adjustment of the electrodes 15 within the plates 14. If desired, a periodical displacement of the electrodes can be carried out by means of a suitable drive (not shown).

In order to obtain a uniform heating of the electrodes, they should be shaped in a suitable manner and an air movement should be obtained which causes the compressed air to uniformly contact with all points of the electrode surface. In order to accomplish this, the electrodes 15 have the shape of circles with relatively long radii with curved end surfaces and the compressed air is introduced into the casing 13 by means of tangentially arranged inlets 19 (as shown in Fig. 3) so that a spiral movement of the air occurs as indicated in Fig. 3 by arrows 20.

In some cases, for instance if the spark gap is used in connection with circuit breakers for large currents, it is not necessary to introduce compressed air into the chamber since the arc by its own heat expands the air contained in the chamber to the extent that it escapes through the nozzle orifices of the electrodes in the same manner as compressed air.

If desired the pressure of the compressed air can be controlled in dependency upon the load in order to provide the minimum air pressure required for extinguishing the arc, because otherwise the efficiency of the device would be diminished. Preferably in the event of high overcurrents or short-circuited currents the air pressure is momentarily increased which can be accomplished by means of an auxiliary vessel containing compressed air of high pressure and connected with the chamber by means of a pipe containing a valve actuated by means of an overcurrent relay or the like. Preferably this relay should interrupt the auxiliary ignition of the arc described herewith.

21 and 22 are throttles arranged within the nozzles 18 and inlets 19, respectively, in order to control the pressure within the casing 13. The throttle valves may be controlled by suitable devices (not shown) in such manner that during the ignition of the arc low pressure exists within the casing and that the air pressure is gradually increased during the burning of the arc so that the highest pressure is obtained when the arc is quenched. The air pressure will then rise to its highest value when the maximum voltage stress occurs in the known rectifying direction. In some cases, for instance if an expensive gas is used, it is advisable to recool the gas after it has been used and to feed it again to the pressure chamber. In order to accomplish this, in Fig. 2 the outer openings of the nozzles 18 are closed by means of end walls 23 provided with outlets 24 connected by pipes 25 to a recooling and pumping device 26 from which the recooled gas is delivered to the inlets 19 by means of pipes 27. The recooled gas exerts a cooling action on the electrodes, which can be increased if the compressed gas is vigorously expanded in the chamber cooled below condensation temperature. If desired saturated steam might be used which is expanded in the pressure chamber in which case the well known arc-extinguishing effect of expanding saturated steam can be utilized. The chemical reaction properties of the electric arc might also be utilized.

In order to further cool the electrodes feed pipes 28 and discharge pipes 29 for recooling fluid are provided. Cooling water or the like is fed by means of pipes 28 to the interstices 30 formed by the outer wall of the electrodes 15 and the walls of the nozzles 18 so that the electrode surfaces being in contact with the base points of the arc are efficiently cooled. Preferably these portions of the electrodes are formed by a metal having a high heat conductivity and high temperature resisting properties.

In order to reduce the ignition voltage and to increase the arcing back voltage, the electrodes are preferably designed with greatly differing shapes as shown for instance in Fig. 1 and in Fig. 4 to be described hereinafter. In these devices the electrode which is positive during the ignition, is sharply curved while the other electrode is relatively flat. In the device shown in Fig. 2 the polarity effect has been renounced too. It should be understood, however, that the different shaping of the electrodes may be used in the device shown in Fig. 2 also.

In order to increase the efficiency of the spark gap particularly in order to adapt it to large outputs, the spark gap should be designed in such manner that the arc burning between the electrodes is relatively short and that it is lengthened immediately before extinguishing the arc which is preferably done a short time before the arc current passes through zero.

A device for accomplishing this is shown in Fig. 4 in which 31 is an insulating casing formed on the inner surface of its mid portion with ribs 32. Each electrode consists of two parts, one surrounding the other. The outer parts 33 and 34 of the electrodes are fitted to the outer ends of the casing 31 by means of a screw thread 35 and 36 so that they are displaceable in longitudinal direction. The members 33 and 34 are hollow cylinders with tapered front portions 37 and 38. Concentrically within the members 33 and 34 are provided, the electrodes 39 and 40, each being provided with a nozzle-shaped orifice 41 and 42, respectively, and fitted in the end walls of the members 33 and 34 by means of screw threads 43 and 43', respectively, so that they are longitudinally displaceable with respect to the members 33 and 34 and to the casing 31. Compressed air is fed through inlets 44 and enters the spaces 45 and 46 between the electrodes 39, 40 and the members 33, 34, respectively. The compressed gas flows with relatively high velocity through the narrow slots 47 and 48 between the tapered portions 37 and 38 of the members 33 and 34 and the electrodes 39 and 40 and enters the space 49 between the electrodes in which the air velocity is relatively small. The base points of the arc are thus driven relatively slowly into the nozzles 41 and 42 of the electrodes. The air pressure and the velocity, the latter by means of throttles 50 provided within the inlets 44 and the outlets 51 for the gas, are controlled in such manner that the base points of the arc reach the nozzles 41, 42 a short time before the current

passes through zero. If necessary the distance between the electrodes and the cross section of the gaps 47 and 48 can be adjusted by displacing the members 33, 34 of the electrodes 39 and 40. The optimum adjustment can be ascertained by means of a wattmeter indicating the power dissipation of the arc. The adjustment of the single parts is correct if the wattmeter shows a minimum power.

If necessary the adjustment can be effected in a different manner for the single electrodes. The adjustments can be carried out if desired during service.

Referring now to Fig. 5, 60 is the casing containing the electrodes 61 and 62 provided with nozzle-like openings 63 and 64. 65 is a sleeve-like movable electrode which can be advanced by means of an actuating rod 66 so that it is pushed over the electrode 61. Therefore during service no arc forms and in order to interrupt the current the movable electrode 65 is withdrawn preferably before the current passes through zero. An arc will then be established between the electrodes 61 and 62 and will be quenched in the manner described in connection with Fig. 1. The compressed air is fed into the casing 60 by means of inlets 66.

In order to avoid non-uniform consumption of the electrode metal during operation it is necessary to cause the base points of the arc to travel along the electrodes. This can be obtained also by means of magnetic fields. I am aware that it is well known to provide magnetic fields in connection with arcing devices, the magnets being arranged in an axis perpendicular to the axis of the electrode in order to lengthen the arc and to blow it out. In the present case, however, such an arrangement would not be advisable since with very high voltages the distance of the magnet winding from the electrode must be made very large in order to avoid flash-overs. In order to avoid this drawback I arrange the magnet coil within the electrode and impart to it the same potential as to the associated electrode. Thus the magnet winding can be located very closely to the arc and magnet fields can be produced which are sufficiently powerful to obtain a high arc velocity.

In Fig. 6 a device of the kind referred to is illustrated. 70 are the electrodes provided with metal sheathed outlets 71 for the compressed gas. 72 are magnet windings fitted to the electrodes, each magnet winding being shielded by the associated electrode so that flash-overs from the opposite electrode are avoided. 73 are current supplies, for instance accumulators feeding the energizing current for the coil 72 by means of connections 74 and 75. 76 are angular casings enclosing the magnet windings and filled with an insulating cooling fluid. The casings are rotated together with the electrodes and magnet windings by means of a shaft 77 rotated in a suitable manner, for instance by means of a gearing 78. Near the ends of shaft 77 gear wheels 79 are provided which mesh with toothed rings 80 secured to the outer walls of the casings 76. In order to maintain connection of the terminals of the windings 72 with the connections 74 and 75 metallic slip rings 81 and 82 are provided within the walls of the insulating casings 76, each slip ring being in contact with a pair of contact brushes for instance 83, 84 connected to connection 75 and winding 72, respectively. The main current is fed to the electrodes 70 in a similar manner by means of a pair of contact brushes 85, 86, and a slip ring 87 provided near the inner wall of the angular casing. As will be seen from the foregoing, by energizing the windings 72 and rotating the casings 76 together with the magnets and the electrodes the base points of the arc will travel in circular paths along the surfaces of the electrodes. In order to drive the base points towards the inlets of the nozzle 71 U-shaped iron rods 88 are provided embracing the windings in the manner shown in Figs. 6 and 8. As seen from Fig. 8 these rods are inclined to the circumference of the windings so as to produce magnetic flux lines indicated in dotted lines in Fig. 8. Flux lines of this arrangement will impart to the base points of the arc not a circular but a spiral way indicated by the arrow 89 in Fig. 8 so that the base points are driven towards the inlet of nozzle 71.

It should be understood that in order to energize the windings any desired current supply, for instance a generator or transformer, might be used. If desired, the windings could be energized with a port of the main current. An arrangement of this kind is shown in Fig. 7, the means for rotating the electrodes being omitted for the sake of simplicity. The main current is fed to the electrodes 70 through connections 90 and 91. 92 is a resistance connected in the connection 90, this resistance being preferably of the kind the value of which is dependent upon the voltage, for instance decreasing with increasing voltage. The windings 72 are connected in parallel with resistance 92 and to each other by means of connections 93, 94, 95 and 96. In this embodiment the electrodes 70 are formed as hollow electrodes provided with inlets 98 and 99 for feeding and discharging the cooling liquid.

The operation of the device shown in Figs. 6–8 is substantially the same as the operation of the device shown in Fig. 1, except that by means of the magnet windings and the rotation of the electrodes a travelling of the base points of the arc is obtained as explained above.

It should be noted that the windings 72 might be replaced by a not-conductive, not magnetic ring provided with a winding. The magnetic field thereby produced could drive the base points of the arc to the nozzle inlet in a straight line. If the electrodes are moved or rotated simultaneously a sufficient arc velocity is obtained.

The invented spark gaps can be excellently employed where periodic ignition of an arc, prolonged burning of an arc, its dependable quenching within a certain time, as well as the requisite safety against re-ignition are necessary, viz. in particular for converting multi-phase alternating current into direct current and vice versa. This converting process can be effected by connecting one or several spark-gaps, complying with the invention, to each phase of the multi-phase system.

At suitable moments, an arc must be produced at these spark-gaps and again quenched at a later moment. To secure an approximately constant direct current, it is firstly necessary that the production of the arc in one phase takes place when the arc in the previous phase still persists. This transition of the current of one phase to the next is in itself difficult to realize with the spark-gap rectifying process. However, according to the invention, this transition is appreciably facilitated in that the initiation of the arc in one phase is undertaken at such a period, that the current in the previous phase

which has to be quenched must compulsively pass through zero a short time later. In this way the quenching conditions of the invented spark-gaps are promoted to a particularly favorable extent. The introduction of an arc can be effected electrically (e. g. by an auxiliary voltage which is established at a certain moment and which sends an ignition current over the spark-gap to be bridged) or mechanically (e. g. by moving the electrodes towards each other entirely or partly bridging the space between the electrodes, etc.). The moment when ignition of each phase has to be effected anew in each period must, however, be accurately determined. The choice of the most suitable moment as well as the practical accomplishment of accurate ignition will be explained by means of an example in which electrical auxiliary ignition is selected.

Referring now to Fig. 9 illustrating a device for converting three-phase current into direct current, 100, 101 and 102 are the secondaries of a three-phase transformer the primaries of which are not shown in the figure for sake of simplicity. The secondaries are connected star-fashion and the star point 103 is connected to ground. 104, 105 and 106 are condensers shunting the secondaries 100, 101 and 102 respectively for a purpose to be explained hereinafter. The secondaries 100, 101, 102 are connected to choke coils 107, 108, 109, respectively. The latter are connected to rectifying spark gaps 110, 111, 112, respectively. The spark gaps are connected to the direct current line 113 leading to the direct current load indicated at 114 and being connected to ground. The spark gaps 110, 111 and 112, are preferably designed in the manner described in connection with Figs. 1–8. The arcs are initiated by means of an auxiliary ignition device described hereinafter. In some cases, for instance, if positive and negative direct voltage is produced and an appreciable capacity exists between the direct current line and ground, it is advisable to connect the star point 103 not to ground but directly to the direct current load 114. The ripple of the direct voltage, particularly if the number of phases is odd, is then very small. Before describing the auxiliary ignition device reference is had to Fig. 10 showing a diagram in which the abscissa is the time and the ordinate the voltage. The sine curves 100, 101, and 102 indicate the voltages of the secondary windings 100, 101 and 102. At the time $t_1$ the voltage of secondary 100 is at its peak value and at this time secondary 100 delivers current through choke coil 107 and spark gap 110 into the direct current line 113. If the load 114 is an ohmic resistance, the current is substantially proportional to the voltage of the secondary winding 100. At the time $t_2$ the voltage of secondary 100 has dropped below the voltage of secondary 101 having increased during the time intervals $t_1$ and $t_2$. At this moment, as will be explained hereinafter, the arc is initiated in the spark gap 111 so that a positive current is fed from secondary 101 to the direct current line 113. Since at this time the voltage of 101 exceeds the voltage of 100, the direction of the current in the spark gap 110 will be reversed and the arc extinguished as explained above in connection with Figs. 1–8. As will be seen from Fig. 10, the time at which the arc in the park gap 111 is initiated, somewhat lags behind the time at which the voltages of the secondaries 100 and 101 are equal. This slight difference of time has an optimum value depending upon the character of the direct current load. It is therefore advisable to design the auxiliary ignition device for the spark gaps in such manner that this difference of time can be adjusted preferably even during service.

Referring now again to Fig. 9 the arcs in the spark gaps 110, 111 and 112 are initiated in the following manner: The terminal of the secondary 100 is connected to an intermediate point 115 of the choke coil 109 by means of a resistance 116 and a capacity 117 connected in series. 118 is a rotating spark gap connecting the intermediate points of resistance 116 and capacity 117 to a point 119 of choke coil 109 intermediate point 115 and the terminal of the choke coil connected to the spark gap 112. Secondary winding 102 is connected to inductance 108 in a similar manner by means of resistance 120, capacity 121 and rotating spark gap 122. Secondary 101 is connected to choke coil 107 in an analogous manner by means of resistance 123, capacity 124 and rotating spark gap 125. Each rotating spark gap consists of two fixed electrodes, for instance 126 and 127 in spark gap 125 and a rotating arm carrying a pair of electrically connected movable electrodes. The rotating arms of the spark gap 118, 122 and 125 are shifted towards each other about 60° and they are adjusted in such manner that each rotating spark gap initiates a flash-over at the moment when the corresponding main spark gap should be ignited. For instance the rotating spark gap 122 should initiate a flash-over at the moment $t_2$. At this time condenser 121 is loaded to a voltage equal to 1½ peak value of the alternating voltage provided that resistances 116, 120, 123 are not too large. When rotating spark gap 122 initiates a flash-over, an oscillation is produced which causes a flash-over between the contacts of the main spark gap 111. The oscillations are drawn off from the secondary 101 by means of the by-pass condenser 105. Some time after the arc of spark gap 111 has been initiated, the rotating spark gap 118 will initiate the arc in spark gap 112 and the arc of spark gap 111 will be extinguished. The arc of spark gap 110 will now be initiated by the rotating spark gap 125 and the arc of spark gap 112 will be extinguished and so on. If it is desired to adjust the difference of time between the ignition of an arc and the moment at which the phase of the arc has the same voltage as the preceding phase, the arms of the rotating spark gaps should be somewhat shifted.

If desired the rotating spark gaps 118, 122 and 125 can be united into a single rotating spark gap comprising three pairs of fixed electrodes and a single pair of rotating electrodes, as will be described hereinafter in connection with Fig. 11.

It should be understood that the igniting device shown in Fig. 9 might be modified in various manners. For instance the capacities 117, 121, 124 might be loaded from other phases or with separate windings. For instance capacity 124 might be loaded by means of two windings, one of which is inserted into the circuit comprising capacity 124 and rotary spark gap 125, the other being inserted into the main line between secondary 100 and spark gap 110. Instead of this the ignition of the spark gap might be obtained by means of voltage shocks, a sinusoidal voltage or the like.

The ignition time can be adjusted in a corresponding manner if conversion is effected by

spark-gaps, the electrodes of which are moved, and with which the path of the arc is periodically opened by shields, etc., or with which ignition and arc quenching is effected by other mechanical ways. In this instance, three processes must be made to coincide as regards time. Namely, the moment indicated in Fig. 10 as $t_2$ must, in view of the above reasons, coincide with ignition of the arc in one phase and on the other hand with the artificial quenching of the arc in the previous phase. If we consider a mechanical rectifier, then in such case the electrodes must be shaped and set in such a manner, that at the moment $t_2$ the electrodes of the phase **101** come in closest proximity, and the electrodes of the phase **100** go away from each other.

Similar conditions obtain in the case of converting direct current into alternating current. In this instance too, the ignition time in one phase can be so selected that the arc in the previous phase is quenched by initiating the new arc. The process is again described in detail by Fig. 9. The same connection can be utilized for converting direct current into alternating current if the ignition time is altered. It is assumed that the direct current line is to feed an existing alternating current network or that the three-phase transformer is fed with alternating current by a small auxiliary generator so that the period of the alternating current voltage is thus provided. The process of ignition and quenching is then as follows: at the moment $t_3$, Fig. 10, the spark gap **111** operates, i. e. direct current flows by way of the arc from **113** via **111** to the phase **101** of the transformer. In order to do this, the voltage of **113** must be higher than that of **101**. The arc at **111** persists up to the moment $t_4$ when the arc is initiated at the spark-gap **112**. As may be seen from Fig. 10, the potential of **102** is lower than that of **101** at this moment; accordingly a positive current must flow from **101** via **111**, **113** and **112** to **102**, i. e. the direction of current in **111** must reverse. The arc in **111** can be extinguished in this moment. This occurs periodically in the other phases. It is evident from this, that in comparison to working from three-phase to direct-current, the ignition time must be advanced. Therefore in the case of converting direct current into three-phase current, ignition must occur approximately before the moment in which the voltages of two phases become equal. The ignition time will have to be selected at different periods, depending upon the kind of direct current network to be fed; in the case of multi-phase service and great capacity in the direct current network, quenching of the arc in one phase is often best effected when the corresponding phase possesses the crest value of its voltage, because in such circumstances the current flowing through the spark gap is at its lowest value. The ignition time of the new arc can therefore be correspondingly advanced. Moreover, when converting positive and negative direct current voltage it is often advisable not to connect the neutral point of the transformer to earth.

By the pertinent selection of the connections of multi-phase transformers and by employing auxiliary inductances, capacities, etc., it must be seen that the transition of current from one phase onto the next is effected as uniform as possible without very sudden alterations in current, and that the voltage across the spark gap at which the arc is quenched cannot reappear too rapidly. Moreover it must be ensured by means of the connections and auxiliary devices, that voltage and current are constant on the direct current side and sinusoidal on the alternating current side.

In order to eliminate the difficulties involved with the former methods of ignition when converting high voltages due to the great distance between electrodes, and in order to ensure reliable ignition particularly in multi-phase operation when the difference of the working voltage between the electrodes is still small, the ignition current and the time during which this ignition current flows in the invented spark gap arc, in accordance with the further invention, made as large as possible, whilst the requisite ignition plant is combined in a pertinent manner.

Fig. 11 shows such arrangement, by means of which the ignition energy attains an appreciable value, in that the capacity and charging voltage of the condensers are increased, whilst the condensers serving to produce the ignition voltage are combined in the individual phases in order to save extra costs.

**130**, **131**, **132** are the secondaries of the three-phase transformer connected in star-fashion with the star point **133** connected to ground. **137**, **138**, **139** are choke coils connected in series with the secondaries **130**, **131**, **132**, **134**, **135** and **136** are capacities shunting the secondary windings and choke coils, respectively. **140**, **141**, **142** are the main spark gaps of the three phases connected to the direct current line **143** by means of the secondaries **144**, **145** and **146** of a Tesla transformer, respectively. The primaries **148**, **149** and **150** of the Tesla transformer are connected with one of their terminals to a condenser **151** and with their other terminals to fixed electrodes **152**, **153**, **154** of a rotating spark gap, the other fixed electrodes **155**, **156**, **157** of which are connected to the other terminal of condenser **151** or to ground. The fixed electrodes of the rotating spark gap forms three pairs of opposite electrodes **152**, **155**, **153**, **156** and **154**, **157**. The movable electrodes are carried by a rotating arm **160** synchronously driven by means of a suitable drive (not shown). The rotating spark gap consecutively connects the primaries **148**, **149** and **150** of the Tesla transformer in shunt to condenser **151**, the latter being loaded from an auxiliary transformer **161** through a rectifier **162**, a large condenser **163** and a resistance **164**. The condenser **163** which is connected between the intermediate point of rectifier **162** and resistance **164** and the connection connecting the secondary of transformer **161** and capacity **151** is a relatively large condenser, the voltage of which does not appreciably change during service. Resistance **164** is dimensioned in such manner that capacity **151** is loaded quickly enough each time after it has been unloaded. It should be noted that a single condenser **151** is provided for all phases and that this condenser is fully charged whenever the ignition takes place independently of the time at which ignition is initiated. If desired, instead of an auxiliary transformer **161** the main transformer might charge condenser **163**. Instead of this the condenser **163** might be charged from the direct line **143**, in which case rectifier **162** might be dispensed with.

In order to produce ignition voltage with a Tesla transformer two methods can be followed, viz. to tune the Tesla circuit to resonance or to apply the so-called shock or impulse excitation. With the former the voltage in the secondary circuit gradually rises to its peak value. With

shock excitation the arrangement must be made in such manner that the voltage in the secondary circuit has already attained its maximum value approximately at the same time as the primary coil has obtained its first voltage. To attain this a particularly close coupling of the two coils is necessary. At high voltages such close coupling can be attained by placing both coils in oil, by distributing the primary coil practically over the entire length of the secondary coil, by using multi-layer secondary coils or by using a section of the secondary coil as primary coil (auto-transformer connection).

The operation of this device is as follows:

When a flash-over is initiated by the rotating spark gap, for instance, when the pair of movable contacts is in opposition to the fixed contacts 152 and 155, as indicated in Fig. 11, a primary circuit of the Tesla transformer is closed through winding 148. Thus a secondary voltage is induced in the winding 144, causing a flash-over in the spark gap 140. Condenser 134 and choke coil 137 are designed in such manner that primary 148 and secondary 144 are in resonance. The resonance current flows from ground to star point 133, condenser 134, spark gap 140, secondary 144, direct voltage line 143 and through capacity 165, existing between line 143 and ground, to ground. These resonance currents have a relatively large intensity and long duration. In certain cases choke coils 137, 138 and 139 might be omitted. Capacity 165 is as a rule formed by the natural capacity between line 143 and ground. If necessary, a bodily condenser can be inserted as indicated in Fig. 11.

The resonance between the primary and secondary windings is not very sharp on account of the inductive windings.

A similar effect is obtained by making condenser 151 very large, since then the primary circuit supplies energy into the secondary circuit due to the short circuit occasioned by flash-over in the spark gap 140.

When the contact arm 160 rotating in the direction of the arrow indicated in Fig. 11, initiates a flash-over between the fixed contacts 153 and 156, a flash-over is initiated in spark gap 141 in a similar manner, and shortly afterwards also in spark gap 142.

In Fig. 12 a modification of my invention is shown in which the ignition voltage is produced by multi-unit impulse generator excitation. For the sake of simplicity merely a single phase is shown in Fig. 12. 170 and 171 are primary and secondary windings forming one phase of the main multi-phase transformer. Secondary 171 is shunted by a condenser 172. Spark gap 173 connects secondary 171 to direct voltage line 174. 175 is a choke coil inserted between direct voltage line 174 and point 176, in which the shock or impulse exciting device to be described hereinafter is connected to spark gap 173.

The shock exciting device comprises the following elements between ground and point 176, connected in series to each other: A spark gap 177, a condenser 178, a second spark gap 179, a second condenser 180, a third spark gap 181, a third condenser 182, a fourth spark gap 183, a fourth condenser 184, a fifth spark gap 185, a fifth condenser 186, an inductance 187, which might be replaced by a long conductor, and a rotating spark gap 188 comprising two fixed contacts 189 and 190 and a pair of electrically connected rotating contacts 191. It should be noted that the number of fixed spark gaps and condensers 177 to 186 is not limited to five, but might be any suitable number. 192, 193, 194 and 195 are resistances connected in series, each resistance shunting a pair of condensers and spark gaps as shown in Fig. 12. For instance resistance 192 shunts condenser 178 and spark gap 179 and so on. 196, 197, 198 and 199 are a similar row of resistances connected in series, each resistance shunting a pair of spark gaps and condensers in the manner indicated in Fig. 12. For instance resistance 196 shunts spark gap 179 and condenser 180. 200 is an auxiliary transformer, the secondary of which is connected to two branches, each branch connecting a rectifier 201, 202 and a resistance 203, 204, respectively. Rectifiers 201 and 202 are inserted in the associated branches with opposite polarity, as shown in the drawings. 205 and 206 are condensers connected in series and connecting the intermediate point between rectifier 202 and resistance 204 with the intermediate point between rectifier 201 and resistance 203. The intermediate point of condensers 205 and 206 is connected to ground. The branch containing rectifier 202 and resistance 204 is connected to the lower terminal of resistance 196, the branch containing rectifier 201 and resistance 203 is connected to the lower terminal of resistance 192, as indicated in Fig. 12. Resistances 203, 204 and 192 to 199 are to be designed in such manner that merely a small portion of the voltage shocks flows off through the resistance, whilst the resistances must allow a periodical charge of condensers 178, 180, 182, 184 and 186.

The operation of this device is as follows:—

Rotating contact 191 of the rotating spark gap initiates a flash-over between the fixed contacts 189 and 190 at predetermined moments, since arm 188 is synchronously driven in the direction of the arrow by means of a suitable drive (not shown). Hereby flash-overs are initiated in the fixed contact spark gaps 177, 179, 181, 183 and 185, so that condensers 178, 180, 182, 184 and 186 charged by transformer 200 through the rectifiers 201, 202 and the resistances 203, 204 and 192 to 199 are connected in series, so that point 176 is charged to a very high voltage, the charging current flowing through inductance 187. Hereby an oscillation is caused, by which the voltage of 176 is increased above the amount provided by the multi-unit condenser. Simultaneously a high frequency oscillation is produced, by which the flash-over voltage of the spark gap 173 is diminished and the duration of the current is prolonged. The igniting current flows from 176 through a spark gap 173 and condenser 172 back to ground, since direct current line 164 is separated from point 176 by the choke 175. The polarity of the voltage shocks must be chosen so that the shock voltage is in phase with the voltage difference existing between the contacts of spark gaps 173, due to the connection of the latter with transformer 170, 171.

Spark gap 172 is preferably designed in the manner disclosed in connection with Figs. 1 to 8.

The effective capacity of the multi-connection should be made larger than would be actually necessary in order to obtain a high voltage. On the other hand the voltage can be made higher than would be necessary in order to initiate a flash-over in spark gap 173. Further the duration of the ignition current can be prolonged by suitably designing choke coil 187.

With single-phase plants rotating spark gap 188 is preferably arranged in the place of spark gap 177, because then it only needs being insu-

lated against ground for a low voltage. In multiphase plants the rotating spark gap is preferably arranged in the place indicated in Fig. 12, since then the rotating gaps of the phases can be united to a single rotating spark gap comprising a single pair of rotating contacts and the number of pairs of fixed contacts corresponding to the number of phases, in a similar manner as the spark gaps shown in Fig. 11. In this case very high flash-over voltages should occur between the fixed and the rotating electrodes, which can be obtained either by spacing widely the electrodes or, for instance, by arranging the spark gaps within a chamber supplied with compressed air.

I wish it to be understood that I do not desire to be limited to the exact details of construction shown and described for obvious modifications will occur to a person skilled in the art.

I claim:—

1. A spark gap comprising a discharge chamber, two electrodes in said chamber and an inlet for feeding compressed gas into said chamber, said inlet being arranged in proximity of one of said electrodes, said inlet having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof and the other electrode being provided with an outlet for the compressed gas having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof.

2. A spark gap comprising a discharge chamber, two electrodes in said chamber and an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with an outlet for the compressed gas having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof.

3. A spark gap comprising a discharge chamber, two electrodes in said chamber and an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with an outlet for the compressed gas having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof, said nozzles having relatively short convergent portions, relatively long divergent portions and curved intake edges so that the arc between the electrodes is initiated at points influenced by the flow of pressure gas and so that the basic points of the arc from the formation until quenching of the arc must travel long paths along said electrodes.

4. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with an outlet for the compressed gas having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof and means for producing a gas flow uniformly playing around said electrodes.

5. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with a nozzle-shaped escaping opening for the compressed gas and means for producing a helical gas flow uniformly playing around said electrodes.

6. A spark gap comprising a discharge chamber, two electrodes arranged in said chamber, means for feeding compressed gas into said chamber, each electrode being provided with an outlet for the compressed gas having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof and means for controlling the gas pressure in said chamber.

7. A spark gap comprising a discharge chamber, two electrodes arranged in said chamber, means for feeding compressed gas into said chamber, each electrode being provided with an outlet for the compressed gas having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof and means for controlling the gas velocity in said chamber.

8. A spark gap comprising a discharge chamber, two electrodes arranged in said chamber, means for feeding compressed gas into said chamber, each electrode being provided with a nozzle-shaped escaping opening for the compressed gas, means for igniting an arc between said electrodes and means for stopping said igniting means and for rapidly increasing the gas pressure in said chamber on the occurrence of a high overcurrent.

9. A spark gap comprising a discharge chamber, two electrodes arranged in said chamber, means for feeding compressed gas into said chamber, each electrode being provided with an outlet for the compressed gas having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof and means for periodically changing the stream of the gas in said chamber.

10. A spark gap comprising a discharge chamber, electrodes arranged in said chamber and means for feeding compressed gas into said chamber, each electrode being provided with an outlet for the compressed gas having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof, said electrodes being shaped differently from each other so as to produce a polarity difference for the flash-over voltages between said electrodes.

11. A spark gap comprising a discharge chamber, two electrodes arranged in said chamber, means for feeding compressed gas into said chamber, each electrode being provided with a nozzle-shaped escaping opening for the compressed gas and means for recooling and returning the gas into said chamber.

12. A spark gap comprising a discharge chamber, two electrodes arranged in said chamber, means for feeding compressed gas into said chamber, each electrode being provided with an outlet for the compressed gas having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof and means for initiating the extinction of the arc just before the current passes through zero with the minimum possible length of the arc.

13. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with a nozzle-shaped escaping opening for the compressed gas and means for producing an electro-

magnetic field for moving the basic points of the arc.

14. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with an outlet for the compressed gas having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof and means for imparting a movement to said electrodes during the burning of the arc between said electrodes.

15. A spark gap comprising a discharge chamber, two electrodes arranged in said chamber and means for feeding, under expansion, saturated steam into said chamber, each electrode being provided with an outlet for the steam having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof.

16. A spark gap comprising a discharge chamber, two electrodes arranged in said chamber, means for feeding compressed gas into said chamber, each electrode being provided with an outlet for the compressed gas having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof and means for controlling the gas pressure and velocity in said chamber in such manner that the arc is extinguished just before the current passes through zero.

17. A spark gap comprising a discharge chamber, two electrodes arranged in said chamber, a nozzle in the wall of each chamber for feeding compressed gas into said chamber, each electrode being provided with a nozzle-shaped escaping opening for the compressed gas and means for controlling the gas pressure before said feeding nozzle and behind said escaping opening.

18. A spark gap comprising a discharge chamber, two electrodes arranged in said chamber, a nozzle in the wall of said chamber for feeding compressed gas into said chamber, each electrode being provided with an outlet for the compressed gas having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof and means for controlling the cross-section of the gas pipe before said feeding nozzle.

19. A spark gap comprising a discharge chamber, two electrodes arranged in said chamber, a nozzle in the wall of each chamber for feeding compressed gas into said chamber, each electrode being provided with a nozzle-shaped escaping opening for the compressed gas and means for controlling the cross section of the gas pipe before said feeding nozzle and behind said escaping opening.

20. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with an outlet for the compressed gas having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof and means for controlling the gas pressures behind said outlets and means for controlling the cross-sections of said outlets in said electrodes, said controlling means for each electrode being independent from each other.

21. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with an outlet for the compressed gas having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof, means for controlling the gas pressures behind said outlets and means for controlling the cross-sections of the said outlets in said electrodes, said controlling means for each electrode being independent from each other and means for actuating by hand said controlling means during running.

22. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with an outlet for the compressed gas having the form of a nozzle the cross-section of which gradually decreases from the ends of the nozzle to an intermediate point thereof, means for controlling the gas pressures behind said outlets and means for controlling the cross-sections of the said outlets in said electrodes, said controlling means for each electrode being independent from each other and means for automatically actuating said controlling means during running.

23. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with a nozzle-shaped escaping opening for the compressed gas and a movable electrode being adapted to electrically connect said first-mentioned electrodes during running and to be displaced shortly after initiating the arc.

24. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with a nozzle-shaped escaping opening for the compressed gas and coils arranged within said electrodes for producing an electromagnetic field for moving the basic points of the arc.

25. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with a nozzle-shaped escaping opening for the compressed gas and coils arranged in the proximity of said electrodes for producing an electromagnetic field driving the basic points of the arc in spiral paths to the openings in said electrodes.

26. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with a nozzle-shaped escaping opening for the compressed gas and coils arranged in the proximity of said electrodes and adapted to be excited by the arc current for producing an electromagnetic field for moving the basic points of the arc.

27. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with a nozzle-shaped escaping opening for the compressed gas, coils arranged in the proximity of said electrodes for producing an electromagnetic field for mov-

ing the basic points of the arc and a current supply for energizing said coils.

28. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with a nozzle-shaped escaping opening for the compressed gas, coils arranged in the proximity of said electrodes for producing an electromagnetic field for moving the basic points of the arc and a cooling fluid container embracing said electrodes.

29. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with a nozzle-shaped escaping opening for the compressed gas, coils arranged in the proximity of said electrodes for producing an electromagnetic field for moving the basic points of the arc and means for rotating said coils.

30. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with a nozzle-shaped escaping opening for the compressed gas, coils arranged in the proximity of said electrodes for producing an electromagnetic field for moving the basic points of the arc and means for rotating said electrodes.

31. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with a nozzle-shaped escaping opening for the compressed gas, coils arranged in the proximity of said electrodes for producing an electromagnetic field for moving the basic points of the arc and means for rotating said coils and said electrodes.

32. A spark gap comprising a discharge chamber, two electrodes in said chamber, an inlet for feeding compressed gas into said chamber, said inlet being arranged in the wall of said chamber, each electrode being provided with a nozzle-shaped escaping opening for the compressed gas, coils arranged in the proximity of said electrodes for producing an electromagnetic field for moving the basic points of the arc and means for imparting substantially equal potential to adjacently arranged electrodes and coils.

33. An equipment for converting high voltage direct currents into alternating currents comprising a spark gap in each phase of the alternating current and a device for periodically igniting the arc in each spark gap shortly before the arc current of the preceding phase passes through zero, said igniting means comprising a Tesla transformer, secondary windings forming part of said Telsa transformer and connected with said spark gap, respectively, primary windings forming part of said Tesla transformer and means for producing a shock excitation in said primary windings.

34. An equipment for converting high voltage direct currents into alternating currents comprising a spark gap in each phase of the alternating current and a device for periodically igniting the arc in each spark gap shortly before the arc current of the preceding phase passes through zero, said igniting means comprising a Tesla transformer, secondary windings forming part of said Tesla transformer and connected with said spark gap, respectively, primary windings forming part of said Tesla transformer and means for producing a shock excitation in said primary windings, the windings of said Tesla transformer being tuned so as to be resonant after the occurrence of a flash-over in said spark gaps.

ERWIN MARX.